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Nutritional composition, functional properties, and sensory acceptability of complementary flour blends from sorghum, pigeon peas, eggplants, and pumpkin seeds

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Abstract

A nutritious complementary flour was formulated using inexpensive and locally available ingredients, and simple household-based preparation techniques (fermentation, roasting, and boiling) were used. Three complementary flour blends (SPEP-1, SPEP-2, and SPEP-3) were made using sorghum, pigeon peas, eggplants, and pumpkin seeds, in the ratios of 60:20:15:5, 55:25:10:10, and 50:30:5:15, respectively. Proximate analysis revealed that moisture (6.89 - 7.89%), ash (3.02 - 4.48%), crude protein (6.17 - 14.96%), crude fat (16.16 - 20.26%), crude fibre (3.10 - 6.69%), and carbohydrate (51.72 - 60.15%) contents of the three flour blends varied significantly ($p < 0.05$). Calcium (236.12 - 312.30 mg/100 g) was the principal mineral, followed by iron (53.67 - 70.32 mg/100 g) and zinc (1.58 - 10.83 mg/100 g). Functional properties analysis was observed as follows: gelatinisation temperature (75.67 - 82.67°C), bulk density (0.63 - 0.69 g/mL), foaming capacity (2.33 - 4.0%), swelling capacity (312.67 - 346.67%), water absorption capacity (189.0 - 206.67%), oil absorption capacity (180.67 - 251.0%), emulsion capacity (11.33 - 16.23%), and emulsion stability (9.57 - 14.83%). SPEP-2 had the highest overall acceptability scores, and compared favourably (20%) with a commercial complementary flour (80%), indicating great potential for the use of underutilised crops such as eggplants and pigeon peas in complementary feeding flour.

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Introduction

Although malnutrition is a problem that affects people of all ages, young children (0.5 - 2 years) are among the most vulnerable (Dukhi, 2020; Oladiran and Emmambux, 2020). Globally, 148.1 million children under five are stunted, and 45 million are wasted, primarily in Asia and Africa. (UNICEF/WHO/World Bank Group, 2023). Undernutrition leads to about 45% of under-five child mortality, with developing nations bearing a disproportionately large share of the burden (Global Nutrition Report, 2018). Approximately, one in every seven children face mortality before their fifth birthday in Sub-Saharan Africa due to malnutrition (Dukhi, 2020). Malnutrition is manifested when children consume food lacking in essential nutrients that help the body to function properly, or the body system is not able to adequately absorb the consumed food (Bhutta *et al*., 2017). In order to reduce childhood malnutrition, it is advisable that infants should be breastfed throughout the first six months of life, and then given nutrient-dense and safe complementary foods while continuing to nurse for up to two years or longer (WHO, 2019). Any nutritious food given to infants between the ages of 6 and 23 months as a supplement to breastfeeding is referred to as complementary food (Arikpo *et al*., 2018). This should exclude sweetened beverages including carbonated drinks, coffee, and tea, which have limited nutritional value. By giving infants a variety of nutritious foods containing vital nutrients, vitamins, and minerals during the complementary feeding period (6 - 23 months), it is possible to prevent all types of childhood malnutrition, including stunting, wasting, micronutrient deficiencies, overweight, and obesity (Seth and Garg, 2011; Arikpo *et al*., 2018). Several commercial

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complementary foods fortified with nutrients are available for fulfilling the nutrient requirements of the infants, but these are often costly and difficult for underprivileged rural communities to obtain. The process of complementary feeding can be made economical, sustainable, and practical for the poor masses in developing countries, if based on local resources and home available foods (Seth and Garg, 2011). Therefore, nutritious complementary flour made from affordable, locally sourced ingredients, and simple household preparation methods is crucial for addressing child malnutrition.

Supplementary foods in Sub-Saharan Africa often lack nutritional value due to their high starch content. In rural areas, the availability and cost of ingredients largely determine the complementary foods provided to infants (Oladiran and Emmambux, 2020). Most commercial nutritious complementary products in Sub-Saharan Africa are expensive and inaccessible to many. Consequently, rural mothers rely on affordable, locally available mixes, primarily cereal porridges made from raw maize. The nutrient composition of sorghum (*Sorghum bicolor* L. Moench) is comparable to that of rice, maize, and wheat (Widowati and Luna, 2022), and has been used as a maize substitute to produce flour blends with promising results in several studies (Adeola *et al*., 2017; Raihan and Saini, 2017; Tobias *et al*., 2018; Mbijiwe *et al*., 2021; Kodak *et al*., 2023). The present work thus aimed to develop a nutritious flour blend utilising inexpensive, easily accessible ingredients (pigeon peas, eggplants, and pumpkin seeds), and a preparation technique that may be used in rural communities. These affordable, nutrient-dense flour blends offer a potential solution to global malnutrition, especially for young children in resource-limited settings, by improving dietary quality and health outcomes for vulnerable populations (Seth and Garg, 2011). A few studies have used pigeon peas (Adeola *et al*., 2017), eggplants (Soares *et al*., 2022), and pumpkin seeds (Mbijiwe *et al*., 2021) to formulate flour blends, and shown that these foods are capable of enhancing the nutritional level of flour blends for complementary feeding. However, no study has formulated a complementary flour blend containing pigeon peas, eggplants, pumpkin seeds, and sorghum. Therefore, the present work formulated three complimentary flours using various ratios of sorghum, pigeon peas, eggplants, and pumpkin seeds, and their nutritional composition, functional properties, and sensory acceptability were assessed.

Materials and methods

Sorghum, pigeon peas, eggplants, and pumpkins seeds were obtained from a market in Blantyre City, Malawi. Materials were cleaned and stored in airtight polyethylene bag at 4°C until further analyses. All chemicals used were of analytical grade.

Preparation of pigeon pea flour

The method described by Olaleye *et al*. (2020) was referred to prepare pigeon pea flour. Briefly, the pigeon peas were immersed in boiling water (100°C) for 20 min, and after draining the water and cooling, the pericarps were removed. After washing, the peas were oven dried at 80°C until a moisture level below 10% was obtained. To ensure nutrient retention, the temperature was kept at 100°C during heating, and 80°C during drying. Using a hammer mill, the peas were milled and then sieved using a 250 µm sieve. The samples were then kept in Ziploc bags at -20°C.

Preparation of eggplant flour

The eggplant flour preparation followed the method described by Thumporn *et al*. (2016). Briefly, the eggplants were washed with water, cut into slices of 5 mm, and oven dried at 50°C for 72 h. Then, the dried slices of eggplants were grounded into powder, and sieved using a 250 µm sieve. The samples were then kept in Ziploc bags at -20°C.

Preparation of pumpkin seed flour

Preparation of pumpkin seed flour followed the method described by Usha *et al*. (2010). Briefly, pumpkin seeds were cleaned with tap water, and sorted to remove any foreign matter or debris. Next, the seeds were uniformly distributed on an oven tray, and roasted in an electric oven at 120°C for 10 min. The time and temperature were carefully maintained to retain nutrients. Controlled roasting at temperatures between 120 and 150°C for 10 - 20 min alters the tertiary structures of proteins, thereby improving their solubility and emulsifying activity index (Tobias *et al*., 2018) Then, the roasted seeds were milled and sieved through a 250 µm sieve. The samples were then kept in Ziploc bags at -20°C.

Preparation of sorghum flour

Preparation of sorghum flour followed a fermentation method described by Hendek-Ertop and Bektaş (2018). Briefly, sorghum grains were sorted to remove damaged seeds and contaminants, then washed with water. Subsequently, 1 kg of the sorghum was soaked into water (1:3, w/v) and the mixture was left to naturally fermented in a bell jar at 28°C for 48 h. After fermentation, the water was drained, and the sorghum grains were washed. Then, the sorghum grains were dried in an oven at 55 ± 5°C for 5 h. The dried fermented sorghum was milled into flour, and kept in Ziploc bags at -20°C.

Preparation of complementary flour blends

The blending ratios of the complementary flours were based on a study by Adeola *et al*. (2017) with some modifications. The prepared flours of sorghum, pigeon peas, eggplants, and pumpkin seeds were combined together in the ratios of 60:20:15:5, 55:25:10:10, and 50:30:5:15, respectively, to produce three blends of complementary flour named SPEP-1, SPEP-2, and SPEPS-3, respectively. The ratios were designed to optimise macronutrients for weanlings. Carbohydrates was provided by sorghum, protein was supplied by pigeon peas, fibre and micronutrients were contributed by eggplants, and healthy fats were added by pumpkin seeds. By varying these ratios, the impact on the overall nutritional profile was assessed, with the aim of achieving adequate protein, healthy fats, and fibre content.

Proximate analysis

The proximate analysis of the flour samples was done in triplicates. Association of Analytical Chemists (AOAC, 2006) methods were referred to determine crude protein, fibre, lipid, moisture, and ash contents.

Protein determination

Determination of crude protein used the Micro-Kjeldhal method (AOAC, 2006).

Determination of moisture

A 2 g of sample was dried in aluminium dishes at 105°C for 5 h. Then, the sample was cooled and weighed again. The loss in weight after drying was then calculated as the percentage moisture (AOAC, 2006) using Eq. 1:

$$\text{Moisture } \% = \frac{W_1 - W_2}{W_1 - W} \times 100 \qquad \text{(Eq. 1)}$$

where, W1: weight of sample plus aluminium dish prior to drying; W2: weight of sample plus aluminium dish following drying; and W: weight of the crucible.

Determination of crude fibre

First, 200 mL of 0.128 M sulphuric acid was added to 10 g of sample, and was heated for 30 min using an electric hot plate. Then, the contents were filtered through a cotton cloth while being washed with warm water until the filtrate's acidity was neutralised. The filtrate was added to 200 mL of 0.313 M sodium hydroxide, and the mixture was heated using an electric hot plate for 30 min. The contents were filtered and washed to completely remove the NaOH residue. The filtrate was then collected in a clean, dried, and pre-weighed crucible. The crucibles were then kept in a furnace at 500°C for 1 h (AOAC, 2006). Crude fibre percentage was calculated using Eq. 2:

$$\text{Crude Fiber } \% = \frac{W_1 - W_2}{W} \times 100 \qquad \text{(Eq. 2)}$$

where, W1: weight of the crucible and fibre prior to drying; W2: weight of the ash and crucible following drying; and W: weight of sample.

Determination of ash content

A sample weighing 2 g was added to a crucible that had already been weighed, and it was then heated to 600°C for 2 h in a muffle furnace. After cooling, the crucible and sample were weighed again. The percentage ash content was calculated using Eq. 3:

$$\text{Ash content } \% = \frac{W_2 - W}{W_1 - W} \times 100 \qquad \text{(Eq. 3)}$$

where, W1: weight of sample plus crucible prior to drying; W2: weight of the sample plus crucible following drying; and W: weight of the crucible.

Determination of crude lipid

A sample weighing 6 g was added to a 22 × 80 mm paper thimble, and cotton wool ball was used to prevent sample loss from the thimble. A 250 mL round bottom flask was weighed and filled with anti-bumping granules. The flask was filled with about 150 mL of hexane, and the apparatus was put together. An electric hot plate was used to reflux Soxhlet extractor connected to a quick-fit condenser for 3 h. After that, the flask was taken out and attached to a distillation equipment set up. This was done to separate hexane from the extracted fat. A desiccator was used to cool the contents of the flask at room temperature. Then, the flask was weighed again, and Eq. 4 was used to calculate the percentage of crude fat:

$$\text{Crude Fat \%} = \frac{W_3 - W_2}{W_1} \times 100 \qquad \text{(Eq. 4)}$$

where, W1: weight of the sample; W2: weight of the round bottle flask; and W3: weight of the round bottled flask with the fat extract.

Determination of total carbohydrates

Carbohydrate was calculated as a percentage difference method.

$$\text{Carbohydrate \%} = 100\% - (\%P + \%F + \%CF + \%A + \%M) \qquad \text{(Eq. 5)}$$

where, P: protein content, F: fibre content; CF: crude fat content; A: ash content; and M: moisture content.

Mineral analysis

First, 0.5 g sample was digested by adding 10 mL of nitric acid, and the contents were allowed to boil until the sample was completely dissolved. Then, the contents were mixed with 2 mL of hydrogen peroxide, and water was used to dilute the contents in a 100 mL volumetric flask. Then, the samples were analysed using Atomic Absorption Spectrometer (AAS).

Determination of functional properties

Swelling capacity

A technique outlined by Okaka and Potter (1977) was referred to determine the swelling capacity. Briefly, distilled water was added to a 100 mL graduated cylinder to make a total capacity of 50 mL after the flour sample had been poured into the 10 mL mark. The contents of the graded cylinder were then blended by upsetting it after the top was carefully closed. After 2 min, the suspension was again upturned, and it was left to stand for an additional 8 min. After the 8th min, the sample's volume was recorded.

Water and oil absorption capacities

A technique outlined by Sosulski *et al*. (1976) was referred to determine the water and oil absorption capacities. The mixture was centrifuged at 3,000 rpm for 30 min. Water or oil absorption was examined as percent water/oil bound per gram flour. The amount of water or oil absorbed was calculated as a percentage of each gram of flour.

Emulsion capacity and stability

The emulsion capacity and stability were determined using the technique given by Yasumatsu *et al*. (1972). A calibrated centrifuge tube was used to prepare the emulsion, consisting of 1 g of flour, 10 mL of distilled water, and 10 mL of soybean oil. The emulsion was centrifuged at 2,000 *g* for 5 min, after which, the emulsion activity was calculated as a percentage based on the relative height of the emulsion layer to the total mixture height. The emulsion stability was determined after heating the emulsion in calibrated centrifuge tube at 80°C for 30 min in a water-bath, cooled for 15 min under running tap water, and centrifuged at 2,000 *g* for 15 min. The emulsion stability, expressed as percentage, was calculated as the ratio of the height of emulsified layer to the total height of the mixture.

Foam capacity

A method provided by Chandra and Samsher (2013) was modified to determine the foam capacity (FC). In a graduated cylinder, 50 mL of distilled water was mixed with 1 g of flour at 30 ± 2°C. The suspension was blended and shaken to foam for 5 min. Using Eq. 6, the volume of foam at 30 s after whipping was given as foam capacity:

$$\text{Foam capacity (\%)} = [(\text{volume of foam AW} - \text{volume of foam BW}) \div \text{volume of foam BW}] \times 100 \qquad \text{(Eq. 6)}$$

where, AW: after whipping, and BW: before whipping.

Gelatinisation temperature

The gelatinisation temperature was determined using the procedure of Shinde (2001). In triplicate, 1 g of flour transferred to 20 mL screw-capped tube. Then, 10 mL of water was added and gradually heated in a water bath until solid gel was formed. The temperature at which complete gel formation observed was recorded and considered as the gelatinisation temperature.

Bulk density

The volume of a 100 g flour sample was determined in a measuring cylinder. The cylinder was repeatedly tapped on a hardwood table until no further volume reduction was observed. The apparent bulk density was then calculated using the final weight and volume measurements.

Sensory evaluation

Using flour blends and water (1:3, w/v), three porridge samples were prepared. The three samples were presented on coded plates, and scored based on how well they tasted, felt in the mouth, looked, and smelled. The degree of likeness of the sample's attributes was assessed using a nine-point hedonic scale, with the following values representing the degree of similarity: 1 = extremely dislike; 2 = dislike very much; 3 = dislike moderately; 4 = dislike slightly; 5 = neither like nor dislike; 6 = like slightly; 7 = like moderately; 8 = like very much; and 9 = like extremely (Ranganna, 1994).

Statistical analysis

IBM-SPSS Statistics version 20 was used to analyse the results. Differences between means were compared by Analysis of Variance (ANOVA), and differences at $p < 0.05$ were considered to be significant.

Results and discussion

Proximate compositions of different blends of complementary flour

Results on proximate composition are shown in Table 1. The amount of moisture in food is one of the main elements impacting its shelf life. Low water activity, which is roughly implied by low moisture content, prevents microorganisms, which are the main cause of food spoilage. Moisture content of the SPEP-1 was significantly ($p < 0.05$) higher than SPEP-2 and SPEP-3. This could have been due to the high amount of sorghum and eggplant in SPEP-1. The moisture contents of SPEP-2 (6.93 ± 0.19%) and SPEP-3 (6.89 ± 0.22%) were comparable to the values reported by Okpala and Okoli (2011), which ranged from 6.85 to 7.46% in flour blends made from pigeon pea, sorghum, and cocoyam. SPEP-3 (14.96 ± 0.06) had the highest crude protein, and SPEP-1 showed the least crude protein (6.17 ± 0.19).

Protein content seemed to increase with increasing pumpkin seeds and pigeon peas proportions in the flour blends. Other studies observed a similar trend, where increasing the proportion of pigeon pea flour in the blends led to higher protein content (Okpala and Okoli, 2011; Fikiru *et al*., 2016; Ukeyima *et al*., 2019). The crude protein content in the present work was comparable to that reported by Ukeyima *et al*. (2019), which ranged from 10.61 to 21.60%. SPEP-1 recorded the highest total ash content (4.48 ± 0.34%), which was similar to the ash content values (0.51 - 3.18%) reported by Ohizua *et al*. (2016). SPEP-3 (3.10 ± 0.15%) had significantly ($p < 0.05$) lower crude fibre values compared to SPEP-1 (5.21 ± 0.12%) and SPEP-2 (6.69 ± 0.04%). Ohizua *et al*. (2016) reported similar findings, with crude fibre content ranging from 0.75 to 2.97% in flour blends made from unripe cooking banana, pigeon pea, and sweet potato.

Since fibre is low in energy and infants' gastrointestinal systems might not be ready to handle high fibre content food, the necessity of reduced fibre in weaning diets has been emphasised (Ekweagwu *et al*., 2008).

SPEP-3 contained the most fat compared to the other two formulations. The crude fat content appeared to increase with increasing pumpkin seed and pigeon pea proportions in the flour blends. In a different investigation in which soybean, groundnut, and rice complementary flour blend was formulated by Eshun *et al*. (2011), values reported were comparable to those seen in the present work.

Due to the significant amounts of sorghum used in the formulations, SPEP-1 and SPEP-2 exhibited higher carbohydrate contents. The most significant and easily accessible source of energy is carbohydrate. The amount of carbohydrates found in the present work was marginally less than what Bello *et al*. (2020) found in their study, which produced flour blends using sprouted sorghum, pigeon pea, and orange-fleshed sweet potato.

In general, the results of the present work were marginally better than those of the research conducted by Fikiru *et al*. (2016), where a complementary flour blend from maize, roasted pea, and malted barley was formulated. Differences in type and mixing ratios of ingredients are vital in determining the moisture content of the complementary flour blend. The moisture and fibre contents of all flour combinations were similar to those of Likuni Phala, a commercial complementary flour (*i.e.*, > 10 and 5%, respectively). While all combinations exhibited higher fat levels than Likuni Phala (6%), they contained less protein than Likuni Phala (15%). This discrepancy could have been due to the fat content contributed by pumpkin seeds. In terms of proximate composition, SPEP-1, SPEP-2, and SPEP-3 met the

Table 1. Proximate composition of different blends of complementary flour.

Flour blend	Composition (%)					
	Moisture	**Crude protein**	**Ash**	**Crude fibre**	**Crude fat**	**Carbohydrate**
SPEP-1	7.89 ± 0.27^{a}	6.17 ± 0.19^{d}	4.48 ± 0.34^{a}	5.21 ± 0.12^{d}	16.16 ± 0.20^{d}	60.15 ± 0.33^{d}
SPEP-2	6.93 ± 0.19^{c}	8.03 ± 0.04^{c}	3.16 ± 0.03^{b}	6.69 ± 0.04^{c}	17.31 ± 0.29^{c}	60.26 ± 0.34^{d}
SPEP-3	6.89 ± 0.22^{c}	14.96 ± 0.06^{b}	3.02 ± 0.23^{b}	3.10 ± 0.15^{e}	20.26 ± 0.12^{b}	51.72 ± 0.27^{e}
Sorghum	3.83 ± 0.10^{d}	4.97 ± 0.24^{e}	2.49 ± 0.11^{b}	2.74 ± 0.09^{f}	8.18 ± 0.18^{e}	78.78 ± 0.61^{a}
Pigeon pea	8.01 ± 0.07^{a}	6.73 ± 0.02^{d}	2.65 ± 0.05^{b}	2.37 ± 0.03^{g}	5.77 ± 0.12^{f}	73.71 ± 0.43^{b}
Eggplant	6.79 ± 0.13^{c}	2.32 ± 0.07^{f}	7.09 ± 0.22^{c}	14.79 ± 0.08^{a}	5.65 ± 0.04^{f}	63.73 ± 0.12^{c}
Pumpkin seed	8.33 ± 0.25^{b}	16.80 ± 0.12^{a}	4.68 ± 0.10^{a}	8.29 ± 0.07^{b}	33.18 ± 0.34^{a}	28.33 ± 0.52^{f}
Codex Alimentarius	< 10%	4.00 - 37.70 g/100 g	< 5%	< 5%	> 7.80%	45 - 65%

Values are means ± SD of triplicate determinations. Different lowercase superscripts in similar column indicate significant difference at $p < 0.05$.

requirements as prescribed by Codex Alimentarius, except for the crude fibre of SPEP-1 and SPEP-2, which were above the required value.

Mineral composition of different blends of complementary flour

The results regarding the mineral content of the various flour blends are displayed in Table 2. SPEP-3 had significantly ($p < 0.05$) higher content of zinc among the three formulations. There appeared to be an increase in the zinc content levels as pumpkin seeds increased in the formulations. Results from a study by Barber *et al*. (2017) on supplementary flour made from fermented maize, soybean, and carrot flours were comparable those observed in the present work. SPEP-2 was significantly ($p < 0.05$) higher in calcium content than the other formulations. In the present work, the iron content ranged from 53.67 - 70.32 mg/100 g in all the formulations. SPEP-2 was significantly ($p < 0.05$) higher in iron content than SPEP-1 and SPEP-3. The findings in the present work were comparable to those reported by Eshun *et al*. (2011), whose study formulated a complementary flour blend from soybean, groundnut, and rice. All three flour blends were above the recommended levels described by Codex Alimentarius (2017). Likuni Phala, a commercial complementary flour, contained significantly lower levels of iron (8 mg) and calcium (100 mg) compared to all flour blend combinations in the present work. The zinc content (5 mg) in Likuni Phala was comparable to that in the flour blends, except for SPEP-1. The difference in mineral content might have been due to variations in the sources and ratios of ingredients used in Likuni Phala compared to those in the present work. While Likuni Phala consists of a corn and soybean blend in a 4:1 ratio, the flour blends developed in the present work included different proportions of sorghum, pigeon peas, eggplants, and pumpkin seeds.

Functional properties of different blends of complementary flour

The results for the various flour blends' functional characteristics are shown in Table 3.

Table 2. Content of selected minerals in different blends of complementary flour (mg/100 g).

Flour blend	Iron	Zinc	Calcium
SPEP-1	53.67 ± 0.07^{c}	1.58 ± 0.05^{f}	236.12 ± 0.35^{c}
SPEP-2	70.32 ± 0.06^{a}	6.22 ± 0.11^{c}	312.30 ± 0.09^{a}
SPEP-3	67.32 ± 0.05^{b}	10.83 ± 0.06^{b}	301.28 ± 0.09^{b}
Sorghum	7.11 ± 0.11^{g}	1.46 ± 0.01^{f}	17.81 ± 0.07^{g}
Pigeon pea	18.68 ± 0.15^{f}	2.62 ± 0.04^{e}	127.75 ± 0.09^{e}
Eggplant	51.57 ± 0.04^{d}	2.14 ± 0.05^{d}	34.78 ± 0.08^{f}
Pumpkin seed	27.32 ± 0.07^{e}	27.33 ± 0.05^{a}	140.28 ± 0.09^{d}
Codex Alimentarius	> 4.84 mg/100 g	> 2.42 mg/100 g	> 435 mg/100 g

Values are means ± SD of triplicate determinations. Different lowercase superscripts in similar column indicate significant difference at $p < 0.05$.

Table 3. Functional properties of different blends of complementary flour.

Functional property	Flour blend		
	SPEP-1	SPEP-2	SPEP-3
G Temp (°C)	75.67 ± 0.94^{b}	80.33 ± 0.94^{a}	82.67 ± 0.94^{a}
BD (g/mL)	0.63 ± 0.10^{b}	0.63 ± 0.10^{b}	0.69 ± 0.10^{a}
FC (%)	2.33 ± 0.39^{b}	3.67 ± 0.38^{a}	4.00 ± 0.39^{a}
SC (%)	337.33 ± 2.86^{a}	346.67 ± 2.87^{a}	312.67 ± 2.86^{b}
WAC (%)	206.67 ± 1.53^{a}	194.67 ± 1.53^{b}	189.00 ± 1.54^{b}
OAC (%)	180.67 ± 2.65^{c}	211.33 ± 2.65^{b}	251.00 ± 2.65^{a}
EC (%)	11.33 ± 0.20^{b}	14.57 ± 0.20^{a}	16.23 ± 0.20^{a}
ES (%)	9.57 ± 0.21^{b}	12.30 ± 0.21^{a}	14.83 ± 0.21^{a}

Values are means ± SD of triplicate determinations. Different lowercase superscripts in similar row indicate significant difference at $p < 0.05$. BD: bulk density; FC: foaming capacity; SC: swelling capacity; WAC: water absorption capacity; OAC: oil absorption capacity; ES: emulsion stability; EC: emulsion capacity; and G Temp: gelatinisation temperature.

Bulk density

According to Adeyeye and Akingbala (2015), bulk density is a measure of the porosity of various food products, and a factor in flour expansion. Higher densities produce porridges that are thick and not suitable for weanlings (Chandra and Samsher, 2013). Flour with bulk densities less than 0.7 mL/g produce thinner porridges, and are recommended for complementary feeding (Adeyeye and Akingbala, 2015). The three flour blends could be suitable as complementary flour for weanlings since their bulk densities varied from 0.63 to 0.69 mL/g, and was less than 0.7 mL/g. The bulk density of SPEP-1 and SPEP-2 were significantly ($p < 0.05$) lower than that of SPEP3, implying that porridge made from SPEP-1 and SPEP-2 will be slightly thinner compared to that of SPEP-3. The low bulk densities (0.63 - 0.69 mL/g) of all three blends could be ideal for creating porridges of appropriate consistency for weanlings. The results were similar to those reported by Asaam *et al*. (2018), who found bulk densities ranging from 0.61 to 0.67 g/mL in yellow maize-soybean-pumpkin composite flour blends. In contrast, Ohizua *et al.* (2016) reported higher bulk densities, varying from 0.48 to 0.92 g/mL, in flour blends made from unripe cooking banana, pigeon pea, and sweet potato.

Gelatinisation temperature

Starch starts to gelatinise at a certain temperature, which is known as the gelatinisation temperature (Chandra *et al*., 2015). In the present work, the flour blends recorded gelatinisation temperatures ranging from 75.67 - 82.67°C. SPEP-1 had a significantly ($p < 0.05$) lower gelatinisation temperature than SPEP-2 and SPEP-3. Lower gelatinisation temperature indicates that it would require less heat in order for the starch granules in the flour to expand and burst, causing the liquid to thicken. Low gelatinisation temperature flour blends are advantageous as complementary flour for weanlings because they require less energy and time to thicken their slurry into porridge. The relatively low gelatinisation temperatures (75.67 - 82.67°C), particularly for SPEP-1, translate to shorter cooking times and reduced energy requirements, which is beneficial in resource-limited settings. This ease of preparation makes these blends practical for caregivers. Chandra *et al.* (2015) reported lower temperature values, ranging from 56.22 to 60.56°C, in a flour blend of rice, green gram, and potato flours.

Foam capacity

The three different flour blends had significantly varied foam capacities ($p < 0.05$). Compared to SPEP-1 and SPEP-2, SPEP-3 recorded a significantly ($p < 0.05$) higher form capacity, which may be explained by the significantly ($p < 0.05$) larger protein content of SPEP-3, as shown in Table 1. The foaming capacity results of the present work (2.33 - 4.00%) were generally lower than those reported by Raihan and Saini (2017), but fell within the range observed by Ohizua *et al*. (2016), which ranged from 2.01 to 12.88%. The ability of proteins to envelop the air bubbles in a continuous, cohesive coating enhances the foaming ability. According to Chandra and Samsher (2013), protein in the dispersion may also the lower surface tension at the water-air interface. Foam enhances palatability, smoothness, lightness, and flavour dispersion, and foaming capacity is an essential property for baking flour. While the foam capacities of the blends were relatively low, thus suggesting limited suitability for traditional leavened baking, they might be suitable for unleavened flatbreads or other applications where aeration is not critical.

Water and oil absorption capacities

Water absorption capacity (WAC), which is measured by how much water a food product can hold after filtering and applying mild centrifugal pressure (Falade and Okafor, 2015), is an important consideration when producing soups, sauces, or oatmeal (Uzo-Peters and Ola, 2020). Comparing SPEP-1 to SPEP-2 and SPEP-3, SPEP-1 had a considerably ($p < 0.05$) better capacity to absorb water, which might have been due to the high concentration of carbohydrate and fibre that came from the high sorghum content. In food, such as porridge, which needs hydration to give good texture and handling qualities, high water capacity is a crucial feature.

Oil absorption capacity (OAC), which describes a protein's capability to bind fat, is an important consideration because lipids are responsible for retaining flavour and enhancing the mouthfeel of foods (Uzo-Peters and Ola, 2020). Compared to SPEP-1 and SPEP-2, SPEP-3 demonstrated a considerably ($p < 0.05$) better oil absorption capability. This might have been due to the high ratio of pumpkin seeds which increased the crude protein and fat levels.

The water absorbing capacity in the present work ranged from 189.00 - 206.67%, and the oil absorbing capacity ranged from 180.67 - 251.00%. Asaam *et al*. (2018) reported similar results of water absorbing capacity ranging 169.61 to 261.02%. Ohizua *et al.* (2016) reported slightly higher water absorption capacity, ranging from 199.60 to 336.58%, and lower oil absorbing capacity, ranging from 92.93 to 154.03%. Chandra *et al.* (2015) reported lower water and oil absorbing capacities which ranged 132 - 142% and 130 - 156%, respectively. In the present work, the flour blends exhibited water absorption capacities ranging from 189.00 to 206.67%, indicating a high ability to absorb water. This high water absorbing capacity is advantageous for achieving optimal porridge consistency, and improving preparation efficiency. Additionally, oil absorption capacity, which measures the ability of flour blends to absorb and retain oils, significantly influences the flavour, mouthfeel, and overall palatability of complementary foods. The flour blends yielded oil absorbing capacity values between 180.67 and 251.00%, reflecting a versatile capacity to bind fats. High oil absorbing capacity contributes to enhanced flavour retention, improved mouthfeel and texture, and increased shelf-life and stability of the complementary foods.

Swelling stability

Comparing SPEP-2 to SPEP-1 and SPEP-3, SPEP-2 demonstrated a considerably ($p < 0.05$) better swelling capacity. According to Asaam *et al*. (2018), the protein and starch content of foods affects swelling capacity. According to Chandra and Samsher (2013), the swelling capacity of flours depends on the size of the particles, the type of variation, and the type of processing methods or unit operations. In the present work, as the amount of eggplant increased, the composite flours' tendency to expand increased as well. The swelling capacities of the flour blends in the present work ranged from 312.67 to 346.67%, which were comparable to the values reported by Asaam *et al*. (2018), who observed slightly higher swelling capacities ranging from 400.00 to 480.29%. The swelling capacity of SPEP-2 (346.67 ± 2.87) indicated its potential for creating stable and textured complimentary food products.

Emulsion capacity and stability

The three different flour mixes varied significantly ($p < 0.05$) in terms of emulsion capacity and stability. Emulsion capacity and stability ranged from 11.33 - 16.23% and 9.57 - 14.83%, respectively. Chandra *et al.* (2015) reported higher emulsion capacity and emulsion stability values for different flours, with emulsion capacity ranging from 41.49 to 44.69%, and emulsion stability ranging from 38.38 to 48.65%. In SPEP-2 and SPEP-3 samples, emulsion stability and capacity were both considerably ($p < 0.05$) higher than in SPEP-1. This could have been due to the higher percentage of pumpkin seeds and pigeon peas, because emulsion formation and stabilisation can be improved by protein emulsion capacity which quantifies the maximum volume of oil that proteins in a specified amount of flour can emulsify (Ohizua *et al.*, 2016) The higher emulsion capacity and stability of SPEP-2 and SPEP-3, could have been due to the increased protein from pigeon peas and pumpkin seeds, thus suggesting their suitability for use in food products requiring emulsification, such as certain types of complementary foods or processed snacks. This opens avenues for developing a wider variety of nutritious and palatable food products for weanlings.

Sensory evaluation

The sensory evaluation of the flour blends, as presented in Table 4, highlights significant variations in overall acceptability, colour, aroma, taste, and mouthfeel among the different formulations. The mean scores for colour, aroma, taste, mouthfeel, and overall acceptability of the different formulations ranged from 3.60 to 4.90, 2.55 to 4.65, 3.40 to 5.90, 2.85 to 5.05, and 3.80 to 6.00, respectively. SPEP-2 received the highest ratings for colour, taste, mouthfeel, and overall acceptability, while SPEP-3 was rated highest for aroma. Comparing SPEP-1 to SPEP-2 and SPEP-3, SPEP-1 performed poorly than SPEP-2 and SPEP-3 ($p < 0.05$) in all sensory attributes. The acceptability of SPEP-2 and SPEP-3 was also considerably ($p < 0.05$) higher than that of SPEP-1. The lower sorghum content and moderate contents of pumpkin seeds and eggplants could explain the high ranking in sensory attributes as well as higher acceptance. Overall, the porridge made using SPEP-2 was the most liked. These results implies that the sensory attributes and overall acceptability were increased by the inclusion of moderate proportions of pumpkin seeds and eggplants into the flour blend. These findings concurred with Mbijiwe *et al*. (2021), who reported that the sensory ratings of flour blend formulations were increased by the inclusion of moderate proportions of pumpkin flour into fermented sorghum flour. Additionally, the results of the present work were comparable to those reported by Adeola *et al.* (2017), who noted sensory scores for complementary foods ranging from 6.00 to 7.27 for viscosity, 5.47 to 6.80 for aroma, 5.40 to 7.00 for taste, and 5.53 to 7.20 for colour. High overall acceptability scores for SPEP-2 suggested that this blend could be highly favoured by the target consumers, thereby enhancing its potential marketability. The high colour scores indicated that SPEP-2 had an appealing visual appearance, which is crucial for attracting mothers who associate vibrant colours with nutritional quality and safety for their children. A pleasing aroma further contributes to the attractiveness of the product, making it more enticing for children and encouraging repeat consumption. Taste is a pivotal factor in the acceptance of complementary foods. SPEP-2's superior taste scores implied that it could be palatable and enjoyable for children, which is essential for consistent dietary intake and nutritional benefits. Additionally, the enhanced mouthfeel of SPEP-2 signified a desirable texture that facilitates easy consumption by infants and young children, thereby reducing the likelihood of rejection based on texture preferences. When subjected to comparison test with a porridge made from a commercial complementary flour, SPEP-2 scored 20% which may be considered favourable, because the commercial complementary flour had other ingredients such as milk, which gave it an advantage.

Table 4. Sensory attributes of different blends of complementary flour.

Flour blend	**Attribute**				
	Overall	**Colour**	**Aroma**	**Taste**	**Mouth feel**
SPEP-1	3.80 ± 0.64^b	3.60 ± 0.54^b	2.55 ± 0.52^b	3.40 ± 0.67^b	2.85 ± 0.57^b
SPEP-2	6.00 ± 0.65^a	4.90 ± 0.54^a	3.85 ± 0.52^a	5.90 ± 0.67^a	5.05 ± 0.58^a
SPEP-3	5.15 ± 0.64^a	4.50 ± 0.54^a	4.65 ± 0.52^a	4.90 ± 0.66^a	3.95 ± 0.57^a

Means ± SD of 20 determinations. Different lowercase superscripts in similar column indicate significant difference at $p < 0.05$.

Conclusion

The present work demonstrated the potential of a complementary flour for weanlings, formulated using a specific blend of underutilised crops: sorghum, pigeon peas, pumpkin seeds, and eggplant. The resulting flours offered valuable nutritional content and acceptable sensory characteristics. Increasing proportion of pigeon peas and pumpkin seeds flours could enrich the flour blend’s nutritional and acceptable sensory attributes. Therefore, this blend could have enormous potential as a complementary flour for weaning in poor and underdeveloped rural communities. Mothers and caregivers in rural communities may be provided with skills and technical know-how of using these particular locally available resources and simple household technologies that might boost the nutritional value of weaning foods for children.

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